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Survey Gear Comparisons and Shark Nursery Habitat Use in Southeast Georgia Estuaries

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by

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DEDICATION

This work is dedicated to the memory of John Hunter Lapelle Jr. (7.22.77-10.29.15), a coastal conservationist, sportsman, and dear friend to many gone too soon. We miss you, buddy!

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(X^2=6.43; p=0.040), whereas adult Atlantic sharpnose shark occurrence was not (p=0.056). Comparisons of proportions of positive sets for juvenile sandbar sharks between estuarine reach revealed not statistically significant differences. In both cases, expected values were fairly small, making X^2 analyses less likely to find significance. All adult Atlantic sharpnose sharks in habitat analyses were males.

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ABSTRACT

Gill nets and longlines were compared as shark nursery sampling methodologies in inshore waters of Georgia to (1) assess differences in gear selectivity, bias, and stress of capture and (2) determine potential relationships between habitat features and shark distribution and abundance. Gear selectivity varied between gears as a function of both species and life stage resulting in significantly different estimates of species and life stage compositions. Juvenile bonnetheads (*Sphyrna tiburo*) and young of the year blacktip sharks (*Carcharhinus limbatus*) experienced significantly higher stress from gill net capture than longline. Major sources of bias are thought to result from dietary preferences and individual size. Juvenile sandbar shark (*C. plumbeus*) distribution revealed a potential preference for creeks rather than sounds, between 0.32-0.8km wide and 4.02-8.05km from the ocean. Adult Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*) appear to prefer larger, open sound waters closer to the ocean. A potential preference for locations in close proximity to jetties over those near oyster reefs was also observed for adult Atlantic sharpnose sharks, and while statistical significance was observed, a stronger pattern may exist, as sample sizes in this study were relatively small yet still able to detect a difference. Future investigations that quantify proportions of habitat availability and shark abundance in a given area may be more useful for identifying preferences for the structures observed in this study. This study also provides strong evidence of finetooth shark (*C. isodon*) primary and potentially secondary nursery habitat in areas that had not yet been

documented. Findings from these investigations can be useful for managers seeking to maintain healthy coastal shark populations.

1. INTRODUCTION

Sharks are fished commercially and recreationally in U.S. coastal and offshore waters and are managed at both the state and federal levels. The life history of most sharks is characterized by relatively slow growth, delayed age at maturity, and the production of few offspring making this group of fishes highly susceptible to overfishing (Hoenig and Gruber, 1990). For these same reasons, the process of rebuilding an overfished shark stock can be relatively slow and difficult compared to that of most teleosts, causing prolonged negative economic (Musick, 1999) and ecological (Ferretti et al., 2010) impacts. Considering the vulnerability of sharks to overfishing, coupled with increasing global catch rates driven by high demand for shark fins and meat, regional fisheries management councils have constructed shark fishery management plans (FMPs) to prevent further overfishing and to rebuild depleted stocks (NMFS, 1993). Recognizing the importance of habitat in maintaining healthy fish populations, current FMPs address the critical need for identifying and describing essential fish habitat (EFH) as mandated by the 1996 Sustainable Fisheries Act (MSFCMA, 1996). Essential fish habitat includes those areas important to fishery stocks for feeding, breeding, or growth to maturity. For many shark species EFH includes coastal estuaries and inshore waters.

Defining critical habitat for coastal species is particularly important with increasing human inhabitance in coastal areas and the associated threats of habitat loss, fragmentation, and modification (Heithaus, 2007). Numerous studies have identified and investigated the dynamics of shark nurseries in Atlantic coastal waters (see McCandless et al., 2007a for review), yet it is still a relatively new area of focus for shark management. Bass (1978) described primary nurseries as areas where sharks are “born and spend the first part of their lives” and secondary nurseries as areas where “older but not yet adolescent or mature sharks” are found. More recently, Heupel et al. (2007) defined shark nurseries as areas where immature sharks: (1) spend more time in than in other areas, (2) display site fidelity, and (3) occur repeatedly across years. According to these definitions, multiple studies provide strong evidence that Georgia’s estuaries serve as critical nursery habitat for several coastal shark species (Gurshin, 2007; Belcher & Jennings, 2009a,b; 2010; Dumont, 2011).

Shark abundance in Georgia’s estuarine nurseries has been most consistently studied using hand-retrieved longlines as a part of the Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) program, a survey designed to identify and assess the use of shark nurseries along the U.S. east coast (NMFS, 1997). Typically, COASTSPAN surveys utilize both longlines and gill nets (McCandless et al., 2007a), however because of tidal effects (i.e., amplitude and velocity) gill nets have not been used in Georgia raising concerns that catches in current shark surveys may not fully reflect true abundance due to survey bias.

Survey bias can be defined as the disproportionate selectivity for, or efficiency in, capturing certain individuals attributable to a given sampling methodology. Bias in fishery-independent surveys may cause certain species or life stages to be absent or result in contrasting estimates of relative abundance made between different methodologies. Survey bias can be due to factors including but not limited to bait type on longlines, mesh size of gill nets, and fish behavior and morphology (Hubert et al., 2012).

Another important consideration when using multiple gear types is the potential stress inflicted on captured individuals. For example, entanglement gears (e.g., gill nets) are known to be more stressful to captured individuals than other passive gears (Hopkins & Cech, 1992). Hopkins and Cech (1992) argued that the restriction of buccal and opercular movements caused by gill net capture were the cause of relatively high physiological stress in captured striped bass. Frick et al. (2010) showed that gill nets capture reduced survivorship and caused greater physiological stress for the gummy shark (*Mustelus antarcticus*) than longline capture. However, the relative stress and survivorship upon being captured as a function of gear type can be species-specific, as Port Jackson sharks (*Heterodontus portusjacksoni*), which did not become constrained over the gills when captured by gill nets, did not have significant differences in stress and survivorship between gears (Frick et al., 2010). One objective of the COASTSPAN survey and others like it is to release individuals in good condition for mark-recapture studies. It is also important to preserve individuals for conservation and stock rebuilding efforts. While it is difficult to determine the absolute survivorship after being captured, describing the relative stress associated with being captured will provide insight into each methodology and its usefulness in achieving management objectives. Thus, there is a need to investigate Georgia's nurseries using gill nets to make direct comparisons to longline surveys for determining potential biases and the relative impacts on captured individuals.

The characterization of shark nursery habitat in Georgia estuaries was most directly tested by Dumont (2011), who described nursery use by sandbar sharks, blacktip sharks, bonnetheads, scalloped hammerheads (*Sphyrna lewini*), and bull sharks (*Carcharhinus leucas*). Several other studies have described shark nursery use in Georgia and nearby northeastern Florida estuaries (Gurshin, 2007; Belcher & Jennings, 2009a,b; 2010; McCallister et al. 2013). In Georgia, weak associations have been described between shark distributions and water quality (Belcher & Jennings, 2010; Dumont, 2011). However, Belcher and Jennings (2010) suggested that larger habitat features might be better predictors of shark distribution. Researchers have often hypothesized that decreased predation risk and resource abundance are the two primary factors governing nursery use by young sharks (Branstetter, 1990; Castro, 1993a; Simpfendorfer & Milward, 1993), and Heithaus (2007) suggested that trade-offs between those factors and individual life-history likely dictate sub-adult shark distribution in coastal estuaries. Therefore investigations of sub-adult shark distribution should consider these tradeoffs and potential associations with different habitat features. Several studies outside of Georgia have found proximity to the ocean to affect sub-adult shark distribution (Grubbs & Musick, 2007; Heithaus et al., 2009; Froeschke et al., 2010). Similarly McCandless et al. (2007b) suggested that areas protected from larger, more open waters by rock jetties were preferred by juvenile sandbar sharks because of refuge from predators and increased prey abundance in Delaware Bay. Fishery-independent shrimp trawl surveys in Georgia were used to examine shark distribution patterns between creek, sound, and offshore waters (Belcher & Jennings, 2009b), which might differ in relative protection from predators or prey species distributions. They found that Atlantic sharpnose sharks were more prominent in sound and offshore waters; however no specific nursery areas for Atlantic sharpnose sharks were identified. In the same study, adult bonnetheads were more likely to be found in creek waters (Belcher & Jennings, 2009b). As a consistent methodology, however, the trawl survey is not practical, as it is an expensive method of sampling for sharks, and it selected overwhelmingly for those two shark species (96.6% of total catch; Belcher & Jennings, 2009b). Gurshin (2007) described spatial shark distribution trends in the Doboy Sound and Duplin River, GA using trammel nets, however sample sizes were notably small and uneven, and the study was limited in duration (three months). Direct studies of habitat associations with shark distribution in Georgia estuaries are limited, and this study was intended to provide new information on the subject and expand upon previous works.

The purpose of this study was to address two gaps in the knowledge and study of Georgia's shark nurseries: (1) how does gill net sampling compare to longline sampling as a survey methodology and (2) how do geospatial and physical habitat features affect estuarine shark distribution. Specifically, the objectives for addressing the first question were to identify and describe differences in selectivity patterns and stress of capture between hand-retrieved longlines and gill nets. Gear comparison information may be useful for: (1) gaining additional insight into which species and life stages utilize Georgia's estuaries as nursery habitat, (2) improving future surveys by increasing efficiency and reducing harmful impacts, and (3) generating more accurate estimates of relative abundance and reducing the amount of uncertainty associated with such indices. To address the second question, shark distributions in nursery habitat were investigated as a function of numerous macro-habitat features: (1) water body width, (2) distance from the mouth of the sound, (3) water body type (i.e. sound, creek/river), and (4) the presence or absence of different types of structure, all of which are features likely to vary in habitat suitability across species and life-stages. This study represents the first use of gill nets to survey Georgia shark nurseries and expands upon previous work by making direct survey methodology comparisons with longline sampling. It also provides the most comprehensive investigation to date of geospatial and physical habitat features, some for the first time, as they relate to shark distribution within Georgia's estuaries.

2. MATERIALS AND METHODS

Study Site

The estuarine waters around St. Simons Island, Jekyll Island, and Cumberland Island consist of many tidal creeks, marshlands, and several prominent rivers emptying into the ocean at the southeast Georgia coastline. The primary rivers include the Frederica, Mackay, South Brunswick, Little Satilla, Satilla, Cumberland, and Crooked Rivers. Sampling of these estuarine waters occurred inshore including sound waters, larger rivers, and smaller creeks and rivers (Figures 1-3). The COASTSPAN survey has monitored shark populations in these waters since 2000, and findings have confirmed that coastal shark species consistently utilize the area as nursery habitat (SEDAR, 2007; Belcher & Jennings, 2009a,b; 2010; Dumont, 2011).

Field Surveys

Ten fixed locations (Figures 2 & 3) were sampled from June through September of 2015 and 2016 using longlines for the annual COASTSPAN survey and were supplemented with gill net sampling at the same locations. Fifty-six additional, experimental locations were sampled using gill nets from April through September of 2016 (total n=110) to assess the potential relationship between shark distribution and habitat characteristics through gill net sampling (Figures 2 & 3). While both gears were never fished at the same time and location, temporal dislocation was minimized to the extent that logistics allowed generating samples amenable to comparison. Sets used for comparisons all occurred in the same month and year. Gill nets were 91.44 m long, 3.65 m tall, and constructed of #177 monofilament with a 10.16 cm stretched mesh. Fifteen pound navy anchors were attached to both ends, and buoys were used to mark each end. A braided nylon bridle stretched from the point of anchor attachment to the net at the beginning of the buoy line. Nets were set parallel to currents to avoid potential difficulties in managing the net due to the large tidal range (~2m) and current velocities experienced in the middle of the South Atlantic Bight. Nets were set at a target depth of 3.65 m (height of net) to prevent individuals from escaping above the net. Nets were allowed to soak for 20 minutes prior to retrieval to minimize mortality of captured individuals.

Longline sampling was consistent with the protocol established by the National Marine Fisheries Service (NMFS, 1997) for the COASTSPAN survey. Longlines were 305 m of braided mainline with 50 gangions, with monofilament leaders and 12/0 hooks baited with Humboldt squid. Lines were allowed to soak for 30 minutes before retrieval. More detailed descriptions of gear dimensions and sampling procedures can be found in (Belcher and Jennings, 2009a) with the exception of gangion type, as monofilament leaders were used in this study.

For both gears, captured individuals were identified by species, sexed, measured for fork (FL) and total lengths (TL), and assessed for umbilical scar condition before release. If non-lethargic, sharks were tagged with a numbered rototag for studies of movement and mortality. Release condition was rated based on observed movement and condition. Individuals that swam off upon release immediately and consistently, even if slowly, were considered “fair-good”. Individuals that hesitated to swim off upon release, displayed minimal fin movement or only gill pumping for a time while being held underwater at the side of the boat before regaining strength to swim off, sank or rotated to a belly-up position for any amount of time, experienced rigor mortis, or were clearly dead were labeled as “poor-dead”. Release conditions were recorded in the field based on two different scales for longline sampling, as GADNR personnel used a 5-point scale in 2015 and UNF personnel used a 4-point scale in 2016. Using the binary categorical system described above (e.g. “good”, “poor”) for analyses was thought to minimize variability due to the subjectivity in observations as well as generate more robust results as analyses were made at the life stage level, where sample sizes where more amenable to analyses using a binary system. Details regarding individual behavior upon release for each possible category were discussed thoroughly with personnel who used the 4-point system to standardize them against personal observations made using the 5-point system before labeling them in binary terms. Because the variation in the classification of umbilical scar condition among and within species appeared to be inconsistent, life stages were assigned based on species and sex-specific length at age information for Atlantic sharks from the literature (Carlson et al., 2006; Drymon et al., 2006; Piercy et al., 2007; Driggers III et al., 2011; SEDAR, 2011; Driggers III et al., 2013; McCandless & Frazier, 2013; SEDAR 2013a,b; Frazier et al., 2014).

Defining and sampling habitat features

Experimental sampling locations were selected using charts, Google Earth Pro®, and on-location visual observations to determine geospatial and habitat characteristics: (1) specific widths of water body, (2) specific distances from the mouth of the sound, (3) water body type (sound or creek/river), and (4) the presence of structure, determined by visual observations at low tide and markers noting submerged reef material. The exact width of the water body at each sampling station was measured in nautical miles using the line tool in Google Earth Pro® then converted to kilometers. Discrete width categories were created and noted as: (1) less than 0.32km, (2) greater than or equal to 0.32km but less than or equal to 0.80km, or (3) greater than 0.80km. Exact distances of each sampling station to the mouth of the sound were measured in nautical miles (then converted to kilometers) using the path tool in Google Earth Pro® by following the main channel (as closely as possible) to the sound entrance. Distance categories used were: (1) less than 4.02km, (2) greater than or equal to 4.02km and less than 8.05km, and (3) greater than 8.05km. Sounds were delineated, using the path tool in Google Earth Pro®, as those areas within the boundary denoted as the approximate terminus of all creeks and rivers and by the mouth of the sound (Figures 1-3). Categories of width and distance from the sound mouth were chosen somewhat haphazardly; however, they were believed to represent discrete habitats that, collectively, represented the extent of potential estuarine nursery habitat and did not necessarily coincide with delineations of sound and creek/river waters.

Each sampling location was also characterized by the presence or absence of structure (e.g., jetties, artificial reefs, natural oyster reefs). At "jetty" stations, nets were set directly up-river, or behind, the jetties. Stations where known artificial reefs were present were sampled by setting nets directly adjacent to the markers delineating the submerged material where the target depth could be achieved. Stations with natural oyster reefs were identified during observations made at low tide and marked on charts for sampling events that occurred at high water. Nets were set adjacent to the oyster reefs on the front, channel-facing side at the target depth. One sample was taken adjacent to a manmade island surrounded by rip-rap, much of which is submerged at high tide, and was thus considered in the "artificial reef" category for analyses. Dissolved oxygen (mg/L), water temperature (°C), and salinity (psu) were recorded for surface and bottom waters (Van Dorn water sampler) during each sampling event while gear was soaking.

Data analyses

Catch per unit effort

Catch per unit of effort (CPUE) was recorded as the number of sharks per 50-hook longline sampling event and as the number of individuals per gill net sampling event. In theory, one could divide catch data from each methodology by a specific length of time to standardize catch rates between gears, however doing so assumes the relationship between effort and time to be linear. This assumption has been shown to be violated for both gill nets (Kennedy, 1951; Austin, 1977; Minns & Hurley, 1988 in Gurshin) and longlines (Gulland 1955; Beverton & Holt, 1957; Gulland, 1969), as fishing power declines as both gears approach saturation making the validity of such comparisons difficult to determine (Belcher & Jennings, 2009b). All CPUEs used in analyses were first examined for normality with the Kolmogorov-Smirnov test. Levene's test was used to determine if variances were homogenous, and in cases where these assumptions were not met, non-parametric or other appropriate tests were used. Statistical significance in all tests was assessed based on an alpha level of 0.05. All analyses of CPUE data were performed using the SPSS statistical software package (v. 24, IBM).

Presence/Absence

Presence/absence data were generated for all species and life stages: positive sets were those that captured at least one individual and negative sets were those that encountered zero individuals. Hypotheses regarding habitat associations were addressed using this categorical information in addition to abundance data analyses to create a more robust investigation. Presence/absence analyses determine associations, whereas analyses using abundance data yield insight to the degree of magnitude of given associations. Although presence/absence analyses answer a slightly different question than those using abundance data, this was thought to be appropriate as patterns from abundance data are likely to become more clear over a longer spanning study due the high variability caused by "zero-catch" sets.

Gear comparisons

Comparisons between gears were made using pairs of data or "sister sets" existed from 2015-2016. Sister sets occurred when each gear was sampled in the same month and year at a given location.

Gear capture efficiency was compared between gears for the aggregate catch and for the three most common species encountered with both gears: bonnetheads, Atlantic sharpnose sharks, and blacktip sharks (*C. limbatus*). Mann-Whitney U tests were used to compare CPUEs between gear types because the data did not meet the assumptions of normality required for parametric analysis (Kolmogorov-Smirnov test, $p<0.001$ in all cases).

Contingency table tests of independence were used to determine if species composition as well as life stage selectivity for Atlantic sharpnose sharks and bonnetheads differed between gears. When using contingency table analysis, the William's correction was applied when expected values were less than five. When tests of independence were significant, comparisons of proportions were used to compare the proportion of individuals of each species relative to the total catch, or the proportion of individuals of each life stage relative to the total catch of a particular species between gears. Stress of capture was also compared between gears, using Fisher's exact probability tests for Atlantic sharpnose sharks, bonnetheads, and blacktip sharks. Since sample sizes were small when data was divided by life stage, Fisher's exact tests were more appropriate than χ^2 tests.

Habitat utilization investigations

The majority of habitat utilization analyses were derived from gill net sampling in 2016, as the fixed locations that year were supplemented with experimental stations which, when taken collectively, were thought to provide sufficient coverage of the key habitat features in question. However, data from 2015 longline sampling was used when analyzing the potential habitat associations among sandbar sharks, as well as young of the year and juvenile Atlantic sharpnose sharks, because this gear type was more efficient at capturing these species. Conversely, longline data from 2016 were not included in these analyses, as samples did not consistently occur across all months, creating potentially confounding effects.

CPUE was compared across habitat factors to determine potential effects of habitat features on shark abundance. As abundance data did not meet parametric assumptions, non-parametric tests were used. For structure type, distance, and width categories Kruskal-Wallis tests were used. Post-hoc pairwise comparisons were generated for groups with significant Kruskal-Wallis results. For structure presence and water body type analyses Mann-Whitney U tests were used.

To evaluate potential effects of width of water body and distance from the mouth of the sound on shark distribution using a different approach, mean widths and distances were compared between positive and negative sets. Catch data were in the form of presence/absence and thus categorical, whereas width and distance data were continuous. Multiple analytical approaches were used to thoroughly assess hypotheses because of the short duration of the study and potential uncertainties associated with non-normal abundance data

Lastly, potential associations were investigated using all categorical information. To determine associations between shark occurrence and water body type as well as the presence of structure, tests of proportions for positive sets were conducted. To determine if shark occurrence was dependent on factors having more than two discrete categories (e.g., structure type, distance from the mouth of the sound, and width of water body), contingency table tests of independence were used. The *G-statistic* was used unless observed values were equal to zero, in which cases the χ^2 *statistic* was used. When tests of independence yielded a significant result, secondary analyses using comparisons of proportions of positive sets between each level of the factor in question were made using the *z-statistic*.

Ranges and means of temperature, salinity, and dissolved oxygen in which all species were encountered were determined to observe distributional preferences based on water quality. Less common species were not analyzed statistically for habitat associations, but general information including gear type, life stage, habitat characteristics at locations of occurrence, and month of occurrence is provided.

3. RESULTS

A total of 662 sharks were encountered during gear comparison and habitat investigations. Across 2015 and 2016, 357 individuals from ten species were encountered in the 114 longline samples used for gear comparisons. Gill net sampling yielded 210 individuals of seven species in the 85 sets used for gear comparisons. Habitat analyses included 204 individuals of five species from 110 gill net samples in 2016 (Table 1). The four most common species captured in longline sets, in order of abundance, were Atlantic sharpnose sharks, bonnetheads, sandbar, and blacktip sharks, which comprised 94% of the total catch. The four most common species captured in gill nets were bonnetheads, finetooth (*C. isodon*), blacktip, and Atlantic sharpnose sharks, making up 97% of the total catch during gear comparison studies (2015 and 2016) and 99% of total catch in 2016 habitat investigations.

Gear comparisons

The total number of sharks captured per sampling event ranged from 0 to 14 for longline sets and 0 to 23 for gill net sets. Overall, aggregate CPUE was significantly higher in longline sets than in gill nets (U=6,461, p=0.007). However, this pattern was species specific. Mean fork length encountered by longlines was 50.6 ±21.2 cm, and mean fork length encountered by gill nets was 56.1±16.2cm.

Of the three commonly encountered species by both gears ($n \geq 15$ in both gears), Atlantic sharpnose sharks were the only species for which capture efficiency was significantly different between longlines and gill nets ($U=8,114$, $p<0.001$), and this pattern was life stage specific. Young of the year (mean FL=31.9±3.6cm) and juvenile Atlantic sharpnose sharks (mean FL=40.4±5.2cm) were captured at a higher rate by longlines than gill nets ($U=7,988.5$, $p<0.001$; $U=5,857.5$, $p=0.036$, respectively). The bonnethead was the most frequently caught of the species commonly encountered both gears (Table 1). Mean fork length of the bonnethead was 58.4±17.7cm in gillnets and 58.0±13.1cm in longlines (Figure 4). The Atlantic sharpnose shark was the second most frequently caught of the species commonly encountered by both gears (Table 1). Mean fork length of the Atlantic sharpnose shark was 59.1±19.6cm in gillnets and 40.7±16.6cm in longlines (Figure 4). The blacktip shark was the third mostly frequently caught of the species commonly encountered by both gears (Table 1). Mean fork length of the blacktip shark was 54.3±4.7cm in gillnets and 60.4±23.0cm in longlines (Figure 4). Although gill nets encountered 34 blacktip sharks and longlines encountered only 16, 19 of these were captured in one gill net set. For species that were common to one gear but not the other, YOY sandbar sharks (mean FL=49.81±7.40) were more efficiently captured by longlines ($U=5,670.5$, $p=0.049$), and YOY finetooth sharks were more efficiently captured by gill nets ($U=4,279.5$, $p<0.001$). Longlines also encountered 10 juvenile sandbar sharks, whereas gill nets encountered none. Conversely, gill nets encountered 6 juvenile finetooth sharks, whereas longlines only encountered 1. Longlines encountered a larger number of species overall (Table 1).

Species composition was dependent on gear (G=198.87; $p<0.001$) when the five most commonly occurring ($n \geq 20$ in either gear) species were grouped individually and those less commonly occurring were grouped together as "other species". Comparisons of proportions revealed that the five main species and "other species" significantly differed between gears. Bonnetheads were a larger proportion of the total gill net catch (44%) than that of longlines (29%) ($z=3.67$, $p<0.001$). Atlantic sharpnose sharks were a larger proportion of the total longline catch (54%) than that of gill nets (12%) ($z=9.92$, $p<0.001$). Blacktip sharks were a larger proportion of total gill net catch (16%) than that of longlines (5%) ($z=4.72$, $p<0.001$). Finetooth sharks were a larger proportion of total gill net catch (24%) than that of longlines (<1%) ($z=9.23$, $p<0.001$). Sandbar sharks were a higher proportion of total longline catch (6%) than that of gill nets (2%) ($z=2.56$, $p<0.010$). "Other species" represented a larger proportion of the total longline catch (6%) than that of gill nets (2%) ($z=2.13$, $p=0.033$) (Figure 6).

Both gears caught all life stages of Atlantic sharpnose sharks and bonnetheads, but of the two, life stage composition was only dependent on gear type for Atlantic sharpnose sharks (G=23.51, $p<0.001$). Longlines were more likely to encounter YOY Atlantic sharpnose sharks (68%) than gill nets (20%) ($z=4.71$, $p<0.001$). Juvenile Atlantic sharpnose shark proportions did not vary significantly between gears (longlines: 13%; gill nets: 20%) ($z=1.03$, $p=0.303$). In gill nets, however, adults were a significantly higher proportion of the total Atlantic sharpnose shark catch (60%) than that of longlines (19%) (z=4.54, p<0.001) (Figure 7). Ninety-eight percent of the adult Atlantic sharpnose sharks were males, with only 1 female being captured during the entire study. Gill nets only encountered YOY blacktip and sandbar sharks, whereas longlines encountered both YOY and juvenile life stages for these two species (Figure 8).

Stress of capture for each species and life stage was compared between gears as the frequency of individuals released dead or in poor condition to those released in fair or good condition using Fisher's exact probability tests. Stress of being captured was significantly greater for bonnethead adults (p<0.001) and YOY blacktip sharks (p=0.017) in gill nets than in longlines (Table 2). This result may be misleading however, as 19 blacktip sharks were caught in one gill net set, and were all released in poor condition because of long processing time. When this set was removed from the analysis, stress was not statistically influenced by gear type (p=0.473). In gillnets, 76% of adult bonnetheads and 68% of YOY blacktip sharks were released in poor condition or worse. Whereas in longlines, percentages were 11% and 25%, respectively (Table 2). Release conditions of poor or worse for juvenile bonnetheads were 13% higher in gill nets than longlines, however this difference was not statistically significant (p=0.070). Stress of capture was not significantly different between gears for Atlantic sharpnose sharks at any life stage (YOY: p=1; Juvenile: p=1; Adult: p=0.246).

Habitat Investigations

Comparing mean CPUE across each habitat factor for each species and life stage yielded significant results in only two cases. Width of water body had a significant effect on the CPUE of sandbar juveniles (Test statistic=8.65; $p=0.013$), and pairwise comparisons revealed that individuals were significantly more frequently encountered in medium width bodies of water than the widest ones, while medium width was seemingly preferred over the most narrow water bodies as well. Secondly, juvenile sandbar abundance was higher in creeks than sounds ($U=1,354.5$; $p=0.041$).

Because of the strong non-normality associated with the CPUE data, an alternative analysis was conducted to determine if the mean widths and distances associated with stations differed between sites where sharks were present and absent. For cases in which longline data was used, only distance was analyzed, because there was minimal variability in width among fixed sampling locations, which was thought to be insufficient for investigating the potential effect of width on shark distribution. Width of water body where adult male Atlantic sharpnose sharks occurred was the only significant case ($t=2.375$, $p=0.019$, $df=108$)(positive sets=1.80±0.85km; negative sets=0.93±0.80km; Figure 9). However, distance from the mouth of the sound was nearly significant for adult male Atlantic sharpnose shark occurrence as well ($t=1.89$, $p=0.061$, $df=108$)(positive sets=3.20±1.27km; negative sets=6.24±3.57km; Figure 9).

Comparisons of proportions of positive sets between creeks and sound waters indicated that juvenile sandbar sharks preferred creeks to sounds ($z=2.07$; $p=0.040$) and that adult male Atlantic sharpnose sharks preferred sounds to creeks

($z=5.31$; $p<0.001$). Comparisons of proportions of positive sets between locations with and without structure revealed no significant associations. The one adult female Atlantic sharpnose shark encountered was found in May in a creek of the widest category.

Tests of independence to determine associations between habitat features with more than two categories (width, distance, structure type) and presence/absence data yielded significant results in two cases. Juvenile sandbar shark occurrence was dependent on distance ($X^2=6.43$; $p=0.040$). Atlantic sharpnose adult male occurrence was dependent on structure type ($X^2=8.44$; $p=0.038$). In both cases 50% of expected values were less than 5, which reduces the strength of the test to find significance. While comparisons of proportions did not find significant differences in the proportions of positive sets between distance categories, 8 of 9 sets positive for juvenile sandbar sharks occurred in medium reaches (n=192), whereas 1 occurred in the lowest reach (n=57)(Figure 10). Secondary analyses using comparisons of proportions for Atlantic sharpnose adult males revealed that the proportion of positive sets was higher at jetties than oyster reefs ($z=1.99$, $p=0.047$), with 1 of 6 sets being positive at jetties compared to 0 positive sets in 23 total sets at oyster reefs. Although Atlantic sharpnose adult male occurrence was not statistically significantly dependent on distance ($p=0.056$), the probability was marginal, and all positive sets occurred in the middle and lower estuarine reaches (Figure 10).

YOY finetooth sharks were encountered at stations with each type of structure and at those with none, both sound and creek waters, and across all levels of both width and distance from the ocean, however no significant associations were identified. Juvenile finetooth sharks occurred in both creeks and sounds, were only in medium and wide bodies of water, and were only found in lower to middle estuarine reaches in the present study, however no significant associations were identified.

Other species encountered included scalloped hammerhead sharks, blacknose sharks (*C. acrontus*), lemon sharks (*Negaprion brevirostris*), and one spinner shark (*C. brevipinna*). Blacknose sharks (11 adults, 1 juvenile) (mean FL=97.3±4.0cm) were almost all encountered by longlines and occurred from June through August, however primarily in July. Blacknose sharks were typically found in wider bodies of water close to the ocean and were near jetties more often than not. Scalloped hammerheads (mean FL=49.7±8.5) were mostly encountered from May through August, with highest numbers in July and August, and 5 individuals were encountered with longlines, whereas 4 of them were encountered by gill nets. Scalloped hammerheads, which were mostly YOY individuals with the exception of 2 juveniles, occurred in medium-wide bodies of water at close to medium distances from the ocean with a slightly higher proportion being found in creeks, and they were almost never found by structure. Three juvenile lemon sharks (mean FL=148.77±4.73cm), 2 in June and 1 in July, were encountered by longlines. All lemons sharks were in wide bodies of water and at medium distances from the ocean, and they were not found at locations with structure. Two of three lemons sharks were in sound waters. One adult spinner shark (FL=75.90cm) was encountered in a wide creek at a medium distance from the ocean where no structure was present.

4. DISCUSSION

This study highlights several differences between longline and gill nets as sampling methodologies within estuarine shark nurseries. Capture efficiency differed between gears for multiple species resulting in significantly different species compositions between gear types. Life stage composition was also found to be affected by gear selectivity. Major sources of selectivity bias are thought to include dietary preference and individual size and morphology. Finetooth sharks are known to prefer teleosts to squid, explaining their near absence from longline samples. Immature Atlantic sharpnose sharks and YOY sandbar sharks could have passed through gill nets, whereas juvenile sandbar and blacktip sharks would have likely bounced off, both cases being the result of size selectivity bias in gill nets. Additionally, the shape of the bonnethead cephalophoil may have increased gill net capture efficiency, even for larger adults. Stress of capture was significantly different between gears types, providing further information on the relatively high stress associated with gill net sampling.

Estuarine shark distribution was shown to have a weak association with the habitat characteristics studied here. Of the factors tested, width of water body and type of water body yielded the most consistent effects on shark distributions. Ecological theory regarding factors such as predator avoidance, feeding opportunity, competition, and individual life history might be useful in interpreting the habitat associations identified in the present study. For example, juvenile sandbar sharks likely prefer relatively narrow and more inland areas because of the reduced risk of predation in these areas compared to larger areas that are closer to the ocean. The life history of sandbar sharks supports this theory as slow growth and reproduction render populations more vulnerable to depletion. In contrast, adult Atlantic sharpnose sharks frequented presumably more dangerous waters. This might suggest greater feeding opportunities, due to reduced competition compared to crowded inland waters, at the expense of greater predation risk, which is not likely as threatening to Atlantic sharpnose populations due to their life history, characterized by relatively fast growth and reproduction. This study also suggests that finetooth sharks potentially utilize the estuaries studied as primary and secondary nursery habitat, a finding that has not been strongly supported in the literature.

Gear comparisons

Bias due to size selectivity is thought to have caused some of the findings in the present study. Hubert et al. (2012) describes the characteristic bell-shaped curve regarding gill-net size selectivity, in that size ranges highly selected for are “quite specific”, and larger and smaller individuals are less likely to be caught. This bias can be caused by mesh size, hanging ratio of the net, type of mesh used (e.g.

monofilament), and strength and flexibility of the mesh type (Hubert et al., 2012). Atlantic sharpnose YOY individuals and juveniles as well as YOY sandbar sharks were likely able to swim through gill nets used in this study, as their mean sizes were smaller than that commonly selected for by the gill nets in this study. This size selectivity bias, which resulted in higher longline selectivity for those three groups of individuals caused much of the observed variation in species and life stage compositions observed between gears in this study.

Similarly, larger individuals that were encountered by longlines were less likely to become entangled by gill nets upon encountering them. While longlines encountered juvenile sandbar and blacktip sharks, gill nets encountered none. Also, other species captured via longline including blacknose sharks, lemon sharks, and one spinner shark were of sizes not likely to become captured by the gill net mesh size used in this study. However, Hubert et al. (2012) noted that in some cases the size selectivity distribution when using a gill net may be slightly bimodal, in which the first peak is due to the characteristic, wedging of individuals, whereas the secondary peak is due to the tangling of larger individuals. Adult finetooth sharks and bonnetheads were captured by gill nets in this study by becoming wrapped up in the mesh, or "tangled", rather than becoming solely wedged. Although bonnethead adults were often wrapped up in gill net mesh, the cephalophoil, with its distinct, shovel-like shape, was often wedged into the mesh so that the monofilament was behind the head. Whether entrapment of the cephalophoil or the wrapping-up of individuals is the initial method of capture was not determined in this study. The cephalophoil of other bonnethead life stages was also observed to be a means of entangling individuals, and this morphological characteristic likely contributes to the efficiency of gill nets in capturing this species.

Dietary preference was another source of selectivity bias likely to have influenced the results. Finetooth sharks, which were readily captured by gill nets, were nearly absent from longlines, and this is probably due to their preference for teleosts. Menhaden (*Breevortia spp.*) especially are highly preferred by immature finetooth sharks (Castro, 1993b; Bethea et al., 2004; Gurshin, 2007). Findings in this study also support those from another study in Georgia estuaries (Belcher & Jennings, 2009a) that found finetooth sharks to occur only on longline hooks baited with spot (*Leiostomus xanthurus*) rather than squid. As finetooth sharks were the only species to be more efficiently captured by gill nets, eliminating this bias in future surveys could provide more detailed surveys of the community composition within Georgia's shark nurseries by including this species. Continued gill net sampling could be supplemented with current longline sampling to achieve this, however, using multiple baits might be the most efficient in terms of time and money spent. To make such a transition, it would be important to compare multi-bait longline catch rates with those from squid-only sets across multiple years to standardize catch rates of the new method.

Bait type has been shown to affect the catch of bonnetheads by longlines, as they are not effectively captured when using teleosts (Ulrich et al., 2007; Belcher and Jennings, 2009a; Dumont, 2011; McCallister et al., 2013). (Belcher and Jennings, 2009a; Dumont, 2011) showed that squid was significantly more effective at capturing bonnetheads. In the present study capture efficiency was no different between sampling methods, and thus it can be concluded that using longlines baited with squid is as effective of a method of capturing bonnetheads as gill nets, which have previously been regarded as the most effective. COASTPAN efforts in nearby areas may benefit from using squid in the future.

Findings in this study are in agreement with previous work showing that gill nets are likely to be more harmful as a survey methodology (Hopkins & Cech, 1992; Frick et al., 2010). This was true for adult bonnetheads and for YOY blacktip sharks. Gill nets often constrict the gills, reducing the ability of captured individuals to pump water of their gills to gather oxygen via buccal pumping, whereas captured individuals on longlines do not experience this limitation and can also move around for ram ventilation, another limitation affecting fish captured by gill nets. Although stress was not statistically different for blacktip sharks when the high catch (19 individuals) set was excluded, the observed stress effects associated with this set support a higher level of stress for this gear. Specifically, when gill nets become more saturated, the length of time required to remove individuals increases the risk of harm to the individuals. Longlines do not impose the same limitations on respiration as gill nets, and as such sharks captured on longlines have lower associated stress. Blacktip sharks have a life history characterized by slower growth and reproduction relative to other common sharks in Georgia estuaries and are thus less resilient to any form of mortality. Considering this along with the relatively low abundance of blacktip sharks in these estuaries, future studies and surveys should consider these findings, as minimizing mortality of blacktip sharks might be more important to sustaining local populations compared to that of other, more common species.

Longlines baited with squid might be the best survey method for studying bonnetheads, as capture efficiency is relatively high and harmful impacts associated with capture are relatively low. However, because the life history of bonnetheads is characterized by relatively fast maturation rates and annual reproduction, the stress associated with gill nets might not be significantly harmful to populations over time.

Neither survey methodology used in the present study had significantly higher rates of poor releases than the other for Atlantic sharpnose sharks of any life stage. Combined with the Atlantic sharpnose life history, marked by fast growth and reproduction, this indicates that current methods of fishery independent surveys used in nursery areas pose little threat to this species.

Findings of this study have implications for the interpretation of shark abundance and distribution data collected in ongoing surveys of shark nurseries in the southeast and other regions. Using squid on longlines, as is the current protocol for COASTSPAN surveys in Georgia, is insufficient for monitoring populations of immature finetooth sharks. Similarly, a 10.16cm stretch gill net mesh is not a practical means of monitoring immature Atlantic sharpnose sharks. While longline sampling appears to be the more efficient and less impactful means of studying the most individuals, gill net sampling, if supplemented to target finetooth sharks, or multi-bait longline surveys would yield more comprehensive assessments of estuarine shark communities in southeast Georgia. The selectivity biases induced by gear type in the current study led to the observed differences among species and life stage compositions between gears. Without an understanding of such biases, making estimates abundance relative to other species or life stages become difficult. Information from this study is directly applicable to fishery management objectives in that the differences observed between gears can be used to improve accuracy when estimating relative abundances by reducing the amount of uncertainty associated with gear bias. Findings regarding capture stress between gears are useful for determining appropriate survey design and ultimately improving conservation efforts.

Habitat utilization investigations

The most consistent trends in habitat preferences within estuarine waters were observed in juvenile sandbar sharks. Findings suggest that these individuals appear to prefer creek waters over sounds, medium widths over large and maybe even small, and that they are potentially more likely to be found at medium distances from the ocean within estuaries. The combination of these findings describes a set of variables, which roughly define a niche for these juvenile sandbar sharks. With slow maturation (13-14 years) and biennial or triennial reproduction (SEDAR, 2011), sandbar sharks likely experience a selective advantage by spending relatively large amounts of time within these areas. Smaller bodies of water that are somewhat removed from immediate access to the ocean are known to be less accessible to larger predatory sharks, providing refuge for smaller, vulnerable sharks. Therefore, sandbar sharks likely solve the ecological trade-off problem described in (Heithaus, 2007) by growing slow in protected areas. This is known to be true on a broader scale, as sandbar sharks, like many others, use inshore waters for nursery habitat (Merson & Pratt, 2001; Grubbs & Musick, 2007), however findings in this study potentially offer a finer resolution at which to describe secondary sandbar shark nursery habitat. Grubbs and Musick (2007) found a negative correlation with juvenile sandbar shark distribution and distance from the ocean in the Chesapeake Bay, however the size difference in study area between that study and the current one do not necessarily make these findings contradictory, as samples in that study were taken over a much larger distance from 0 to 75km from the ocean.

Atlantic sharpnose adult males were also observed to have potential habitat preferences within the estuary. Wider bodies of water, especially sounds, closer to the ocean were areas where sampling was more likely to encounter these individuals. Belcher and Jennings (2009b) suggested that Atlantic sharpnose sharks do not have a specific nursery area in coastal Georgia. This idea was also described by Carlson et al. (2008), who suggested that juvenile Atlantic sharpnose sharks move between several coastal bays, potentially seeking the highest quality feeding environments, rather than remaining in one discrete, protected area. While no nursery habitat was identified in the present study, the habitat features investigated largely explained the extent of the use of inshore waters by adult male Atlantic sharpnose sharks. It is possible that this apparent aversion to further inshore, narrower waters exists as a result the increased competition for resources with immature sharks associated with the more confined space. This potential aversion would be supported by findings from (McCallister, 2013), in which, although potential prey items were more highly distributed in creeks than sounds, Atlantic sharpnose abundance did not reflect this pattern. Therefore, more open waters might offer relatively higher prey abundance while simultaneously increasing predation risk, a risk which is relatively less threatening to Atlantic sharpnose sharks considering their life history, characterized by relatively fast growth and reproduction.

The finding that almost all adult Atlantic sharpnose sharks were males is consistent with findings elsewhere in the coastal Atlantic (Abel et al., 2007; Ulrich et al., 2007; McCallister, 2013) and Gulf of Mexico (Parsons and Hoffmayer, 2005). This sexual segregation suggests that adult female Atlantic sharpnose sharks do not spend much time inshore, and Abel et al. (2007) suggested that pupping and mating occurred outside of sound waters in the Gulf of Mexico. In contrast, McCallister (2013) observed the only mature female captured in his study giving birth in sound waters in northeast Florida in May. The one female encountered in this study was found in a creek in May suggesting a potential inshore pupping event, however primary pupping sites are not likely not in the inshore waters of the current study.

Atlantic sharpnose adult males appear to prefer areas near rock jetties to those alongside oyster reefs. Although prey may be abundant around oyster reefs, foraging efficiency may be lower than that at rock jetties. This mechanism was described by Heithaus (2007), who cited multiple studies (Morrissey and Gruber, 1993; Bush and Holland, 2003) in which complex structured habitat such as seagrass beds and shrimp burrows likely reduce shark foraging efficiency and affected shark distribution. It is also possible that the adult male Atlantic sharpnose sharks are inferior competitors to other individuals near oyster reefs, and therefore even if desired prey abundances were relatively high at oyster reefs, adult male Atlantic sharpnose shark occurrence would not be expected to reflect prey abundance. This potential competitive displacement in fish is described in (Sutherland and Parker, 1985; Parker and Sutherland, 1986), both of which challenge the Ideal Free Distribution model (Fretwell and Lucas, 1970) with considerations of "unequal competitors" and "phenotype-limitation". However, further research examining the diet and distribution of adult male Atlantic sharpnose sharks, potential competitors, as well prey distribution would be needed to test these ideas on competitive displacement.

Finetooth sharks appear to utilize Georgia estuaries as primary and secondary nurseries with no specific habitat preferences. Previous studies in nearby areas support this finding, however, the present study provides the strongest support for this claim in Georgia. Ulrich et al. (2007) described primary finetooth shark nursery in South Carolina estuarine waters, which are similar to Georgia estuaries, as characterized by numerous barrier islands and vast expanses of salt marshes and tidal creeks. Gurshin (2007) described the Sapelo Island National Estuarine Research Reserve, a Georgia estuary north of the current study area, as finetooth shark nursery. However, this conclusion was based on the occurrence of sub-adult sharks in estuarine waters rather than the relative proportion of sub-adults compared to adjacent nearshore and offshore waters, and was only one year in duration, and thus does not meet the current criteria for defining nursery habitat described in (Heupel, 2007). Personal observations, as a member of the GA DNR adult red drum (*Sciaenops ocellatus*) survey, using squid and mullet as bait on longlines in nearshore and offshore waters of Georgia indicate that YOY and juvenile finetooth sharks utilize estuarine waters more often. Although all criteria for nursery habitat were not met, this study provides the strongest evidence to date of finetooth shark primary and secondary nursery habitat in Georgia estuaries. Future studies should sample adjacent nearshore and offshore waters to the estuaries of the present study to directly test for finetooth nursery. Also, while one YOY individual from this study was recaptured by a recreational fisherman in the same estuary (C. Belcher, personal communication), additional information from mark and recapture studies and acoustic telemetry would be useful in determining if individuals display site fidelity, a third criterion for defining nursery habitat (Heupel, 2007). The occurrence of finetooth sharks across all levels of each habitat features investigated and without significant associations suggests that they likely do not experience a significant disadvantage in the form of increased predation risk by moving among habitat types, which yields a relatively large area in which they can forage. In contrast to finding YOY finetooth sharks in all reaches of the estuary in the present study, Gurshin (2007) found them only in lower reaches of estuarine waters, however sampling was infrequent in other areas, and the overall number of sampling events was low. Ulrich et al. (2007) indicated an overlap between nearshore and estuarine waters for nursery habitat of juvenile finetooth sharks in South Carolina, which is supportive of findings in the current study where finetooth sharks occurred more commonly in medium and wide bodies of water in the middle and lowest estuarine reaches. Therefore, secondary nursery appears to overlap with primary nursery, however not completely.

Extending the duration of this study or similar ones would be a valuable improvement for future work. This would allow for an increased number of observations, yielding a better understanding of the year-to-year variation. This study could also be improved by addressing the habitat preference question by quantifying the amounts of different habitats available and determining the use of those habitat in relation to their relative abundances as suggested in (Simpfendorfer and Heupel, 2004). Perhaps quantifying the distances from structure of each sampling location would be a beneficial supplement to this approach as well. Since sharks are highly mobile foragers with relatively generalized diets, it might be difficult to determine the preference for oyster reefs, for example, by examining individual stretches of reef. Instead, associations and preferences might be more easily determined from a broader spatial perspective in which the amount of oyster reef in a given area is considered, to expand on that specific example.

5. CONCLUSIONS

This study highlights important differences between two commonly used gears for shark nursery surveys, and it provides new information on the use of Georgia's estuaries as nursery habitat, both of which should be useful to fishery managers. Longlines using squid are more selective for YOY and juvenile Atlantic sharpnose sharks and immature sandbar sharks than gill nets, whereas gill nets are more selective for YOY finetooth sharks. Longlines are also more likely to encounter a wider array of species due to the higher selectivity of larger individuals. Distance from the ocean, width of water body, and water body type can be useful in describing immature shark distribution in Georgia estuaries, but continued investigations are needed to provide strong support for these findings. Alternative methods and continued investigations should be considered for assessing potential effects of structure type of shark distribution in Georgia estuaries. Finetooth shark nursery habitat was suggested through gill net sampling, which would be newly identified nursery habitat for this species if this were confirmed with additional studies. Maintaining nursery habitat is an important part of ensuring sustainable shark populations, and long term monitoring surveys as well as investigations to describe the use of nursery habitat are fundamental in addressing this objective. Understanding the characteristics of survey methodologies, including the biases and limitations, is important for increasing survey and sampling efficiency and effectiveness. Also, information from this study can be used to improve estimates of abundance and reduce the amount of uncertainty associated with those estimates. Identifying intra-nursery habitat associations can be useful for understanding the processes affecting nursery community dynamics as well as improving habitat protection and restoration efforts, an important area of focus considering that harmful human impacts are an increasing threat to coastal areas.

Figure 1. Map of study site and sampling locations.

Figure 2. Map of sampling locations around the St. Simons Sound. Fixed locations for COASTPAN survey are indicated by clusters of gill net and longline samples.

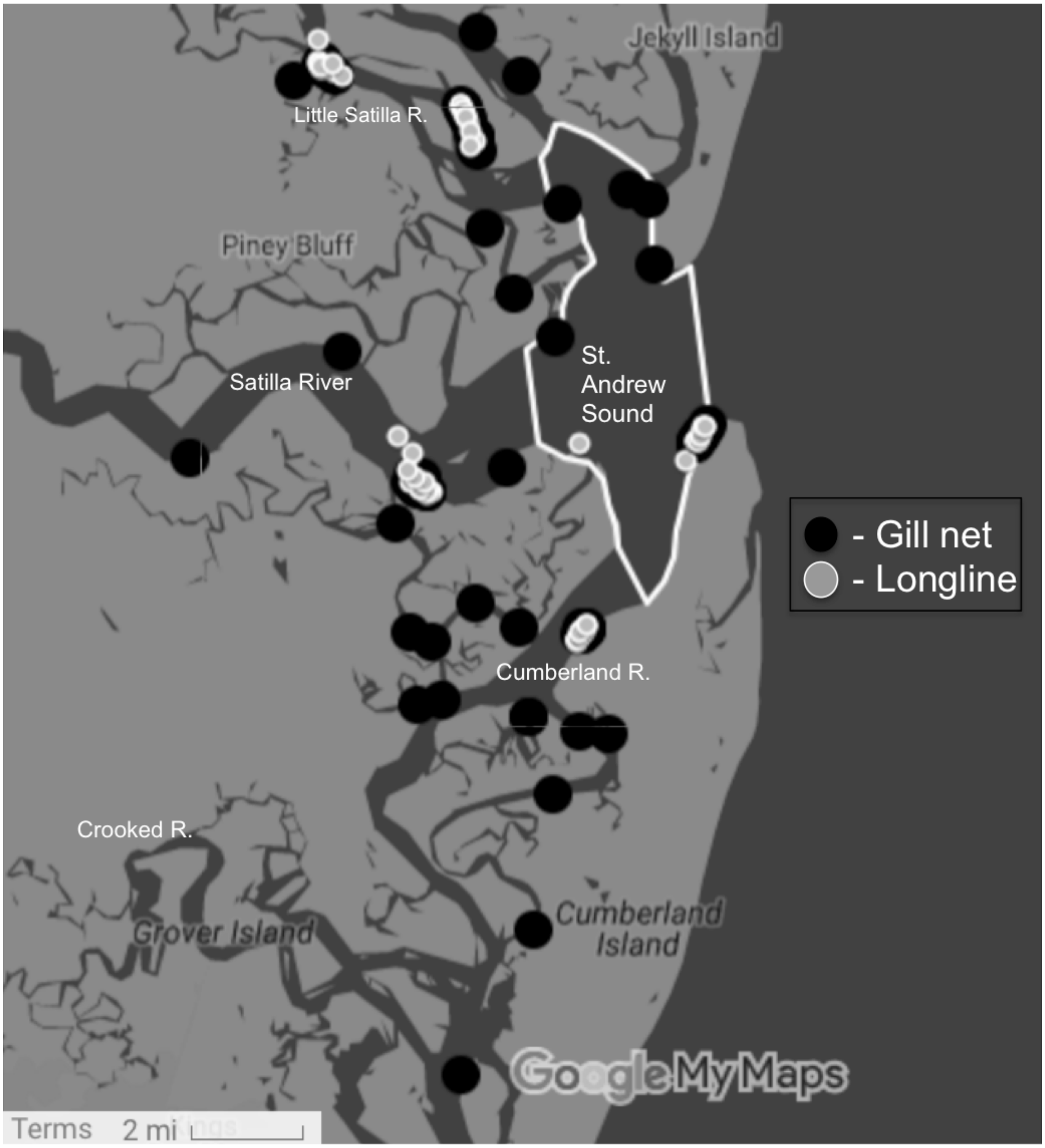

Figure 3. Map of sampling locations around the St. Andrew Sound. Fixed locations for COASTPAN survey are indicated by clusters of gill net and longline samples.

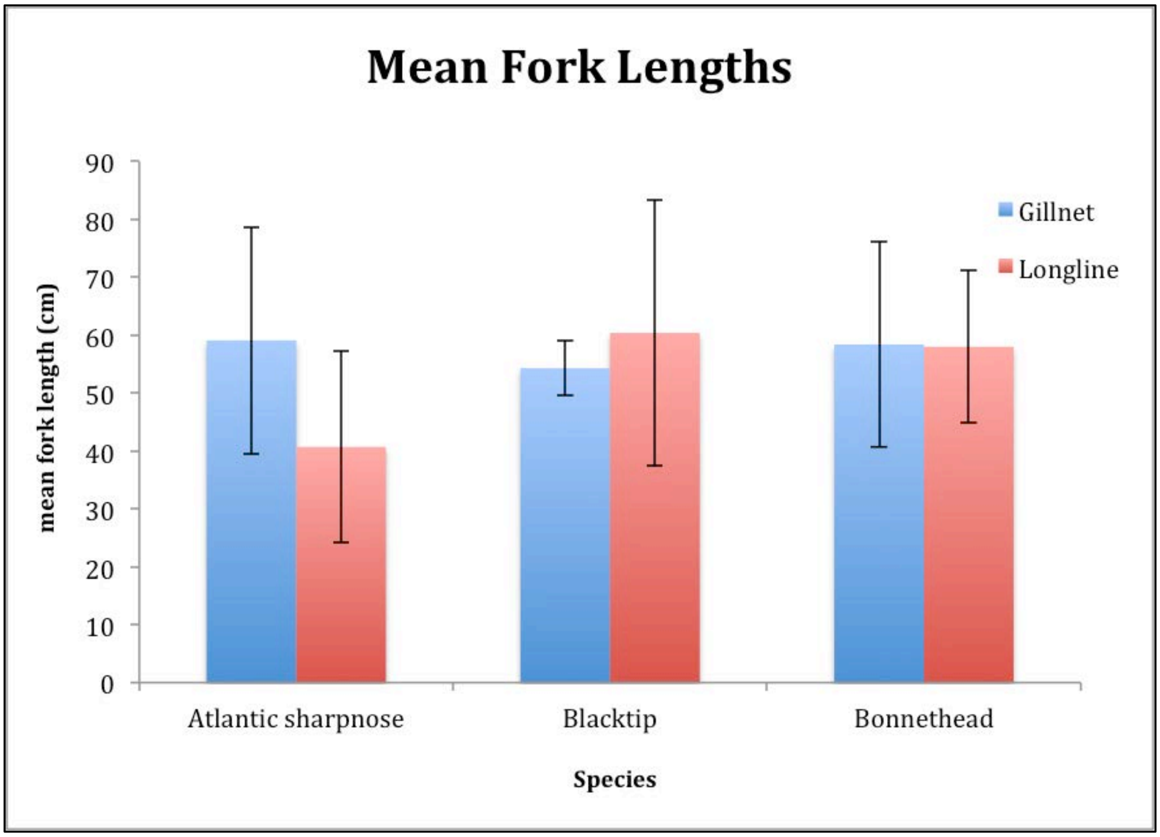

Figure 4. Mean fork lengths with error bars representing standard deviation of the three most commonly encountered (n≥15) species by both gears.

Table 1

Catch by year and gear type, and water chemistry (salinity: parts per thousand; temperature: degrees Celsius; dissolved oxygen: mg/L) ranges and means for all species by life stage. Catch by year, gear, and life stage also shown for the aggregate catch.

Species		Longline		Gillnet		Salinity (psu)		Temperature (°C)		D.O. (mg/L)	
	Total	'15	'16	'15	'16	Range	Mean	Range	Mean	Range	Mean
Bonnethead	251	56	44	49	102						
YOY	6	1	-	3	2	24.5-33.7	30.4	27.1-30.8	29.3	4.5-5.7	5.0
Juvenile	183	42	38	33	70	12.9-36.4	28.9	21.6-31.3	28.3	3.1-7.8	5.6
Adult	62	13	6	13	30	13.2-33.3	28.5	23-31.5	28.5	3.2-7.0	5.5
Finetooth	73	1	1	26	45						
YOY	66	-	1	22	43	22-33	30.6	22.8-31.3	29.5	4-6.7	5.5
Juvenile	7	1	-	5	1	13.2-34.4	28.7	29-30.8	30.1	4.7-7.0	5.5
Adult	3	-	-	2	1	25.5-32.7	28.8	24.2-27.1	25.8	4.5-6.7	5.9
Blacktip	61	5	11	9	36						
YOY	58	3	10	9	36	12.9-33.7	30.6	24.3-31.5	30.0	4.0-6.3	5.3
Juvenile	3	2	1	-	-	27.5-30	28.8	28-29.5	28.8	4.7-6.4	5.5
Atl. sharpnose	217	102	88	8	19						
YOY	137	72	58	2	5	12.9-36.2	30.2	26.1-31.2	28.4	3.3-7.3	5.5
Juvenile	29	7	17	3	2	25.5-34.8	31.9	27.8-30.8	29.7	4.3-8.4	5.6
Adult	52	24	13	3	12	22.2-32.2	27.6	23.2-30.7	26.6	3.3-7.0	6.0
Sandbar	25	17	5	3	-						
YOY	14	8	3	3	-	20.2-34.6	27.6	23.8-30.4	28.3	4.3-8.4	6.1
Juvenile	11	9	2	-	-	22.3-34.8	28.3	22.1-30.1	27.4	3.5-7.4	5.9
Blacknose	12	10	1	1	-						
Juvenile	1	1	-	-	-	-	36.2	-	28.9	-	5.5
Adult	11	9	1	1	-	28.9-32.7	29.8	27.1-28.2	27.7	4.5-6.9	6.0
Scalloped H.H.	9	-	5	2	2						
YOY	6	-	3	2	1	29.4-33.3	31.5	28.2-30.8	29.8	5.5-6.7	6.1
Juvenile	3	-	2	-	1	-	26.1	-	23.3	-	6.1
Lemon	2	2	-	-	-						
Juvenile	2	2	-	-	-	-	26.8	-	26.9	-	6.39
Spinner	1	1	-	-	-						
Adult	1	1	-	-	-	-	12.9	-	27.6	-	5.31
Aggregate Catch	654	194	155	101	204						
YOY	287	84	75	41	87						
Juvenile	239	64	60	41	74						
Adult	129	47	20	19	43						

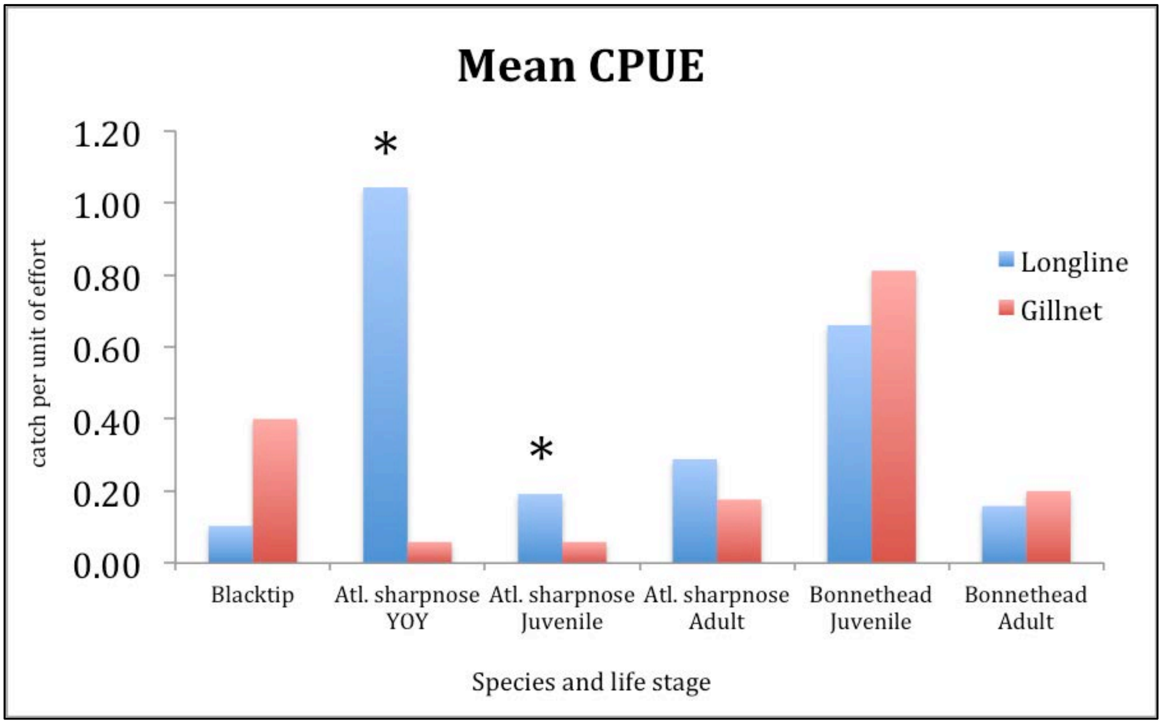

Figure 5. Mean catch per unit of effort (CPUE) by gear for blacktip sharks, Atlantic sharpnose sharks, and bonnetheads at various life stages. Asterisks denote significance in mean CPUE comparisons.

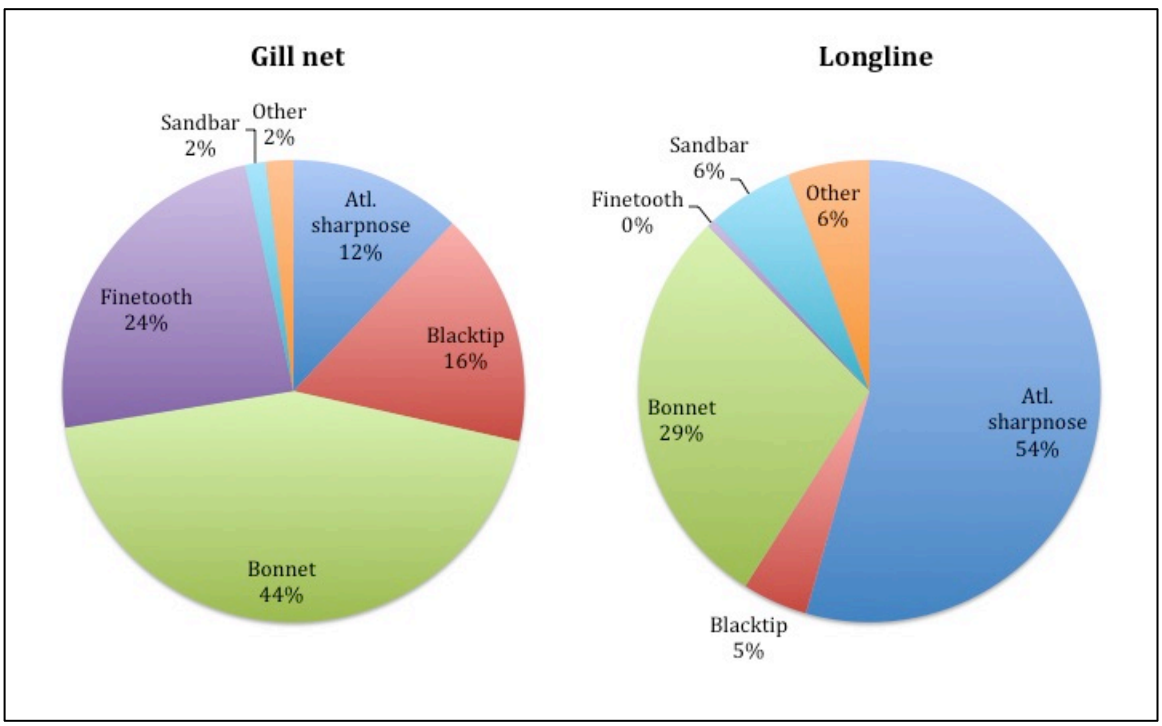

Figure 6. Proportionate catch of each species during gear comparison study.

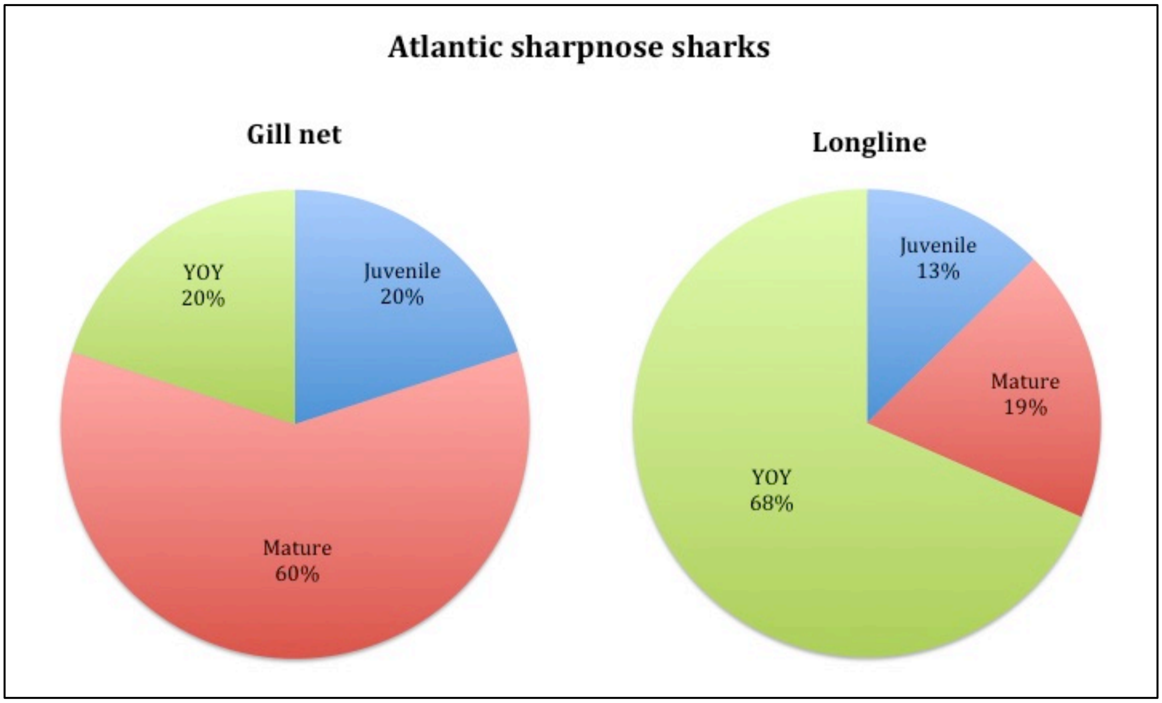

Figure 7. Proportionate catch of each life stage by gear for the Atlantic sharpnose shark during gear comparison study.

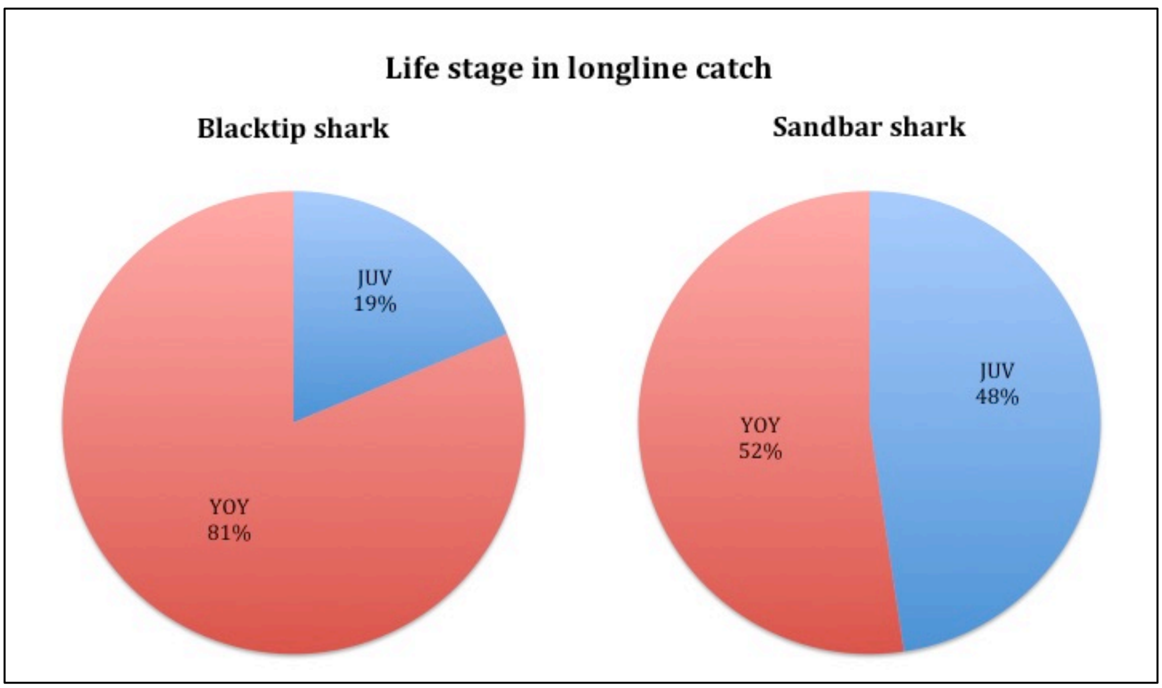

Figure 8. Proportionate catch of YOY and juvenile individuals for blacktip and sandbar sharks by longlines. Gill nets only encountered YOY individuals of both species.

Table 2

Contingency tables used to determine dependence of "stress of capture" on gear type. Asterisks denote significantly higher stress of capture in gill nets. Proportion of total catch by gear shown in parenthesis.

Species		GN	LL	Total
Bonnethead Juvenile	*Poor/Dead*	19 (28%)	12 (15%)	31
	Fair/Good	49 (72%)	67 (85%)	116
	Total	68	79	147
Bonnethead Adult*	*Poor/Dead*	13 (76%)	2 (11%)	15
	Fair/Good	4 (24%)	16 (89%)	20
	Total	17	18	35
Blacktip YOY*	*Poor/Dead*	23 (68%)	3 (25%)	26
	Fair/Good	11 (32%)	9 (75%)	20
	Total	34	12	46

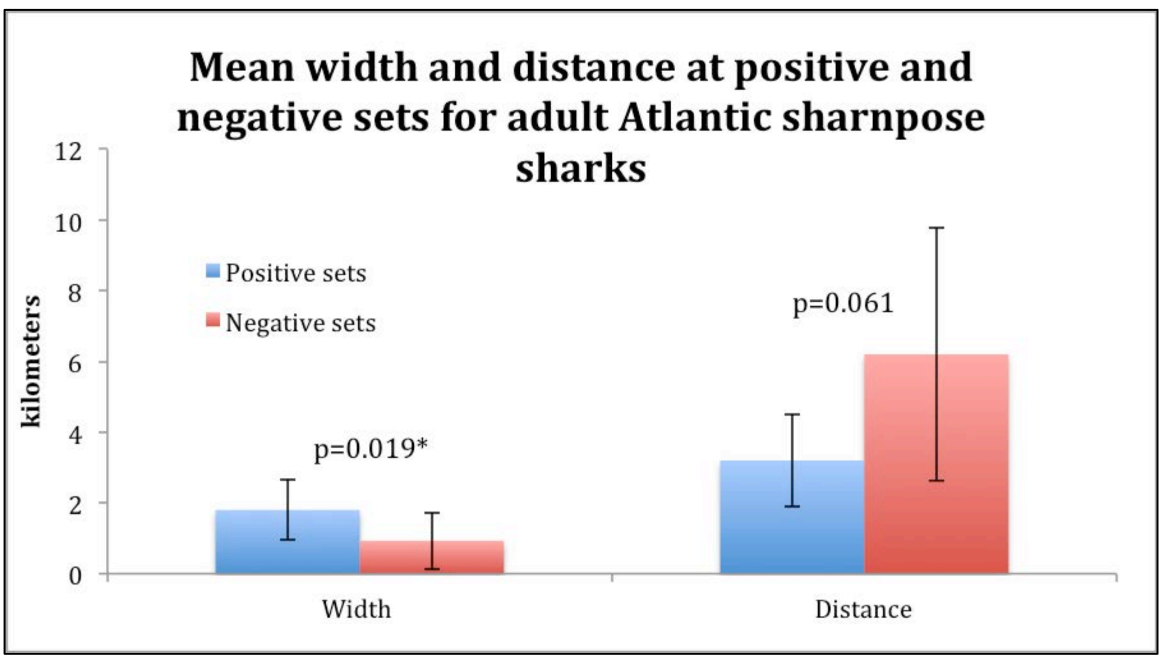

Figure 9. Mean width and distance with error bars denoting standard deviation for positive and negative sets of adult Atlantic sharpnose sharks. P-values from t-tests are shown above each cluster, with asterisks denoting statistical significance. All adult Atlantic sharpnose sharks in habitat analyses were males.

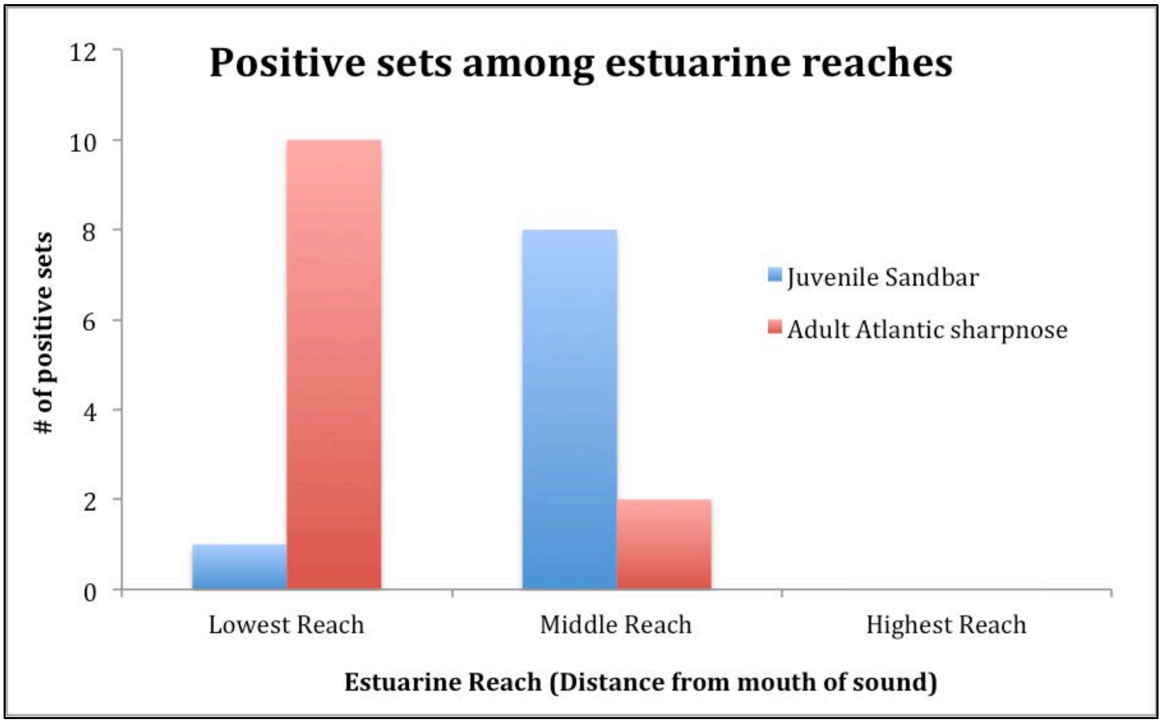

Figure 10. Amounts of positive sets for juvenile sandbar sharks and adult Atlantic sharpnose sharks are shown as a function of estuarine reach. Juvenile sandbar shark occurrence was statistically significantly dependent on estuarine reach (X^2=6.43; p=0.040), whereas adult Atlantic sharpnose shark occurrence was not (p=0.056). Comparisons of proportions of positive sets for juvenile sandbar sharks between estuarine reach revealed not statistically significant differences. In both cases, expected values were fairly small, making X^2 analyses less likely to find significance. All adult Atlantic sharpnose sharks in habitat analyses were males.

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